Electronic ignition

The traditional winter morning sight of motorists battling to breathe life into frozen engines is becoming less common as modern ignition systems are made to brave harsher and harsher climates. There is though still room for improvement before the "I know a man who can" man can look forward to a lie-in.

Electronic ignition systems started life as an after sales add-on, the latest gimmick to beat the old mechanically switched system. They were invariably capacitor discharge systems and for good reasons: the standard ignition coil was still there.

Inductive discharge systems were not possible without a change of coil due to a lack of high voltage power switching transistors. It was the HV power bipolar transistor that changed things.

Unfortunately by then the standard coil had come to the end of its life in favour of low inductance coils with ballast resistors to improve cold starting. Thus the bipolar transistor was called to switch about 6A. To do so reliably, safe operating clamps were needed raising costs and dissipation.

Power mosfets on the other hand are majority carrier devices and are not subject to second breakdown, so they do not need safe operating area clamping. The suitability of power mosfets has sometimes been overlooked because of concern over the mosfets resistance due to the high voltage rating required. But all the necessary specifications can be met including crank voltage performance with a higher efficiency than typically found in systems using bipolar transistors.

Today's ignition modules have not changed dramatically over the years but higher efficiencies can be achieved using a lower current high inductance coil. Ignition requirements for modern engines fall into four categories – aiming voltage at the spark plug, available energy from the coil, spark duration, and crank voltage.

The aiming voltage requirement is the open circuit voltage at the high tension terminal of the coil before the inter-electrode gap of the spark plug breaks down. This should not be confused with the arc voltage across the spark plug's gap after breakdown. The aiming voltage is normally specified as 16kV at a minimum battery voltage of 13.2V. It should be as high as possible without endangering coil winding insulation so that it can fire fouled plugs.

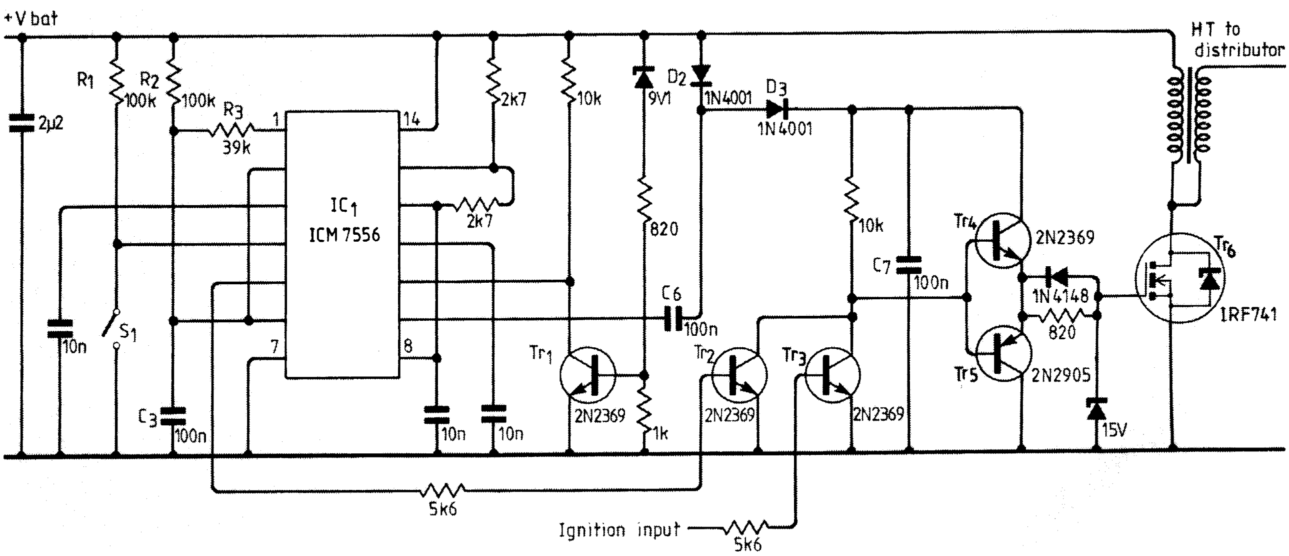
Fig.1. IC1 acts as a charge pump bias generator to provide 10V enhancement voltage for Tr6 during starting when battery voltage may fall below 6V.

Minimum available energy from the coil can be as little as 2mJ, though engine specifications frequently quote 6mJ for a crank voltage of 6V. Extrapolating for a crank voltage of 4.5V gives a minimum energy of 4mJ. Too high an energy level will accelerate spark plug electrode erosion.

Many variables determine the requirements for spark duration including the number of cylinders, maximum revolution rate of the engine, fuel and air mixture in the combustion chamber, and static ignition timing when the engine is idle.

Consider an eight cylinder engine running at 6000rev/min. The maximum time interval between the start of one spark and the next is about 2.5ms. Crankshaft angular velocity is 360° in 10ms, or 1° in 27.8μs. Centrifugal advance can be up to 21° btdc (before top dead centre). Frequently quoted spark durations for capacitor discharge systems of 400μs are normally considered adequate.

If the dwell time is 1.8ms maximum then a spark duration of 700μs should be adequate to avoid detonation due to premature extinguishing of the flame front. On the other hand, if the same engine is idle at 800rev/min, the maximum time between the start of one spark and the next is about 18.75ms. Crank shaft angular velocity is 360° in



75ms or 1° in 208μs. The spark advance at static idle may be 6° btdc.

Here the 400μs spark duration seriously increases the chance of the flame front being prematurely extinguished when the spark stops. This is more likely in modern fuel efficient lean-burn engines.

The volt-second product balance for inductive discharge systems should provide a spark at idle that is long enough to prevent detonation.

Crank voltage can be defined as the available battery voltage while the starter motor is operating. Various specifications for 12V cars place this at 6V and in some particularly bad cases as low as 4.5V.

A bipolar Darlington transistor and a 4mH coil limited to 6A will provide an aiming voltage of 12kV. An 8mH coil limited to 3.5A with a mosfet can provide an aiming voltage of 13kV. Therefore both systems perform equally well with the mosfet system consuming less power and thus being more efficient.

Furthermore, a bipolar Darlington transistor with an 8mH coil would only generate an aiming voltage of 9kV at a crank voltage of 4.5V. This may not be enought to fire the plugs. The 4mJ coil and Darlington would be adequate for the 4.5V crank voltage but power consumption would increase.

To design a mosfet ignition system, the first priority is to pick a coil with as low a primary current as possible. Primary inductance should be a nominal 8mH, and primary resistance should not be less then 2.5Ω and not more than 3.75Ω. The turns ratio of the coil should be a nominal 55:1.

The recommended mosfet for the power switch is the IRF741 which will give a maximum clamped aiming voltage of 19kV for a minimum drain-to-source breakdown voltage (BV_{DSS}) and 21kV for a maximum BV_{DSS}. These aiming voltages will not cause internal breakdown in the coil. The maximum BV_{DSS} assumed here is the minimum BV_{DSS} of the prime voltage version of the IRF741 and 740.

This combination will give an aiming voltage during cranking at 4.5V of 10kV minimum, and a spark energy of 4.7mJ. The specified minimum is typically 4mJ. Spark duration is 150μs minimum. For an eight cylinder engine, the maximum power consumption is 17W at 6000rev/min and 25W at 800rev/min. These correspond to 32 and 42W, respectively, for a 4mJ coil and Darlington bipolar transistor.

The circuit diagram (**Fig.1**) shows a practical ignition module with built-in test oscillator composed of R1, R2, R3, C3 and half of IC1. This provides a 50Hz 50% duty cycle pulse to the base of Tr2 with S1 open. With S1 closed, normal ignition triggering is via the ignition input, with input high when Tr6 is off.

Tr1, D2, D3, C6, C7 and the second half of IC1 comprise a gated charge pump for maintaining adequate gate voltage for Tr6 for battery voltages less than 10V during cranking. Tr6 avalanches repetitively and absorbs the energy stored in the leakage inductance of the coil.

Fig. 2 shows the waveforms of HT voltage (upper trace) and drain source voltage (lower trace) across Tr6. The battery voltage is 4.5V and the HT terminal is not terminated. It appears that the spark duration comes to about 150μs but, as can be seen from the waveform in Fig. 3, it is somewhat longer in practice.

In **Fig. 3** the time base has been changed to 200μs/div and the lower trace sensitivity to 200V/div. The upper trace sensitivity stays the same. The waveforms show the gap breaking down at about 9kV with the arc sustaining voltage about 2kV. From the lower trace it is clear that the spark duration is about 200μs for a maintained battery voltage of 4.5V.

Fig. 4 shows the waveform with the bridgeable air gap set to 12mm and the battery voltage set to 14V. This would be the minimum voltage during charging that would be seen as typical in a car. The HT waveform is the upper trace and V_{DS} of Tr6 is the lower waveform.

The gap breaks down at about 16kV while the arc is maintained for about 1ms. The 500V drain source spike is caused by the leakage inductance of the coil and plays no part in the spark generation. This can be seen in Fig. 5 where the time base speed has been increased to 1μs/div.

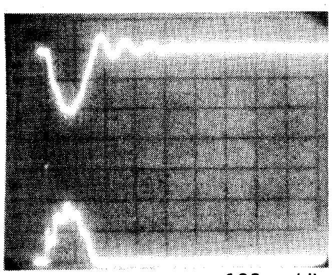
In **Fig. 5** the HT voltage has only reached about 2kV by the time the leakage reaction spark starts to diminish. The magnitude of the leakage spike amply displays avalanche in the mosfet and this avalanche capability will stop the HT voltage from exceeding a nominal 22kV with an IRF741 for Tr6.

The waveforms in all the photographs were obtained at a frequency compatible with an engine speed of 6000rev/min for an eight-cylinder engine. At idle the increased dwell angle would increase the magnitude of the HT aiming voltages in Figs 2 and 3.

Maximum power consumption at 800 and 6000rev/min was 21.5 and 16.8W, respectively, and is in line with design specifications.

The ignition module in the circuit diagram gives a performance similar to that of any of the better systems available without any sacrifice in cost. It provides savings in power consumption and heat generation, a measure of its reliability. ■

HT voltage 5 kV/div

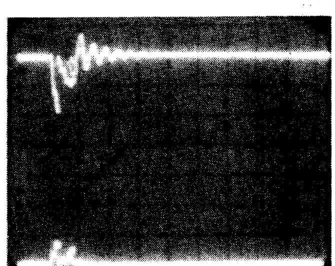


V_{DS} 100V/div

100 μs/div

Fig.2

HT voltage 5 kV/div

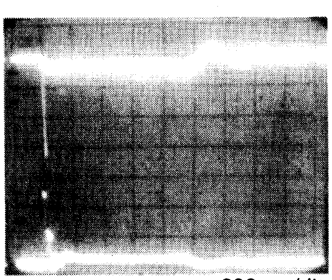


V_{DS} 200V/div

200μs/div

Fig.3

HT voltage 5 kV/div

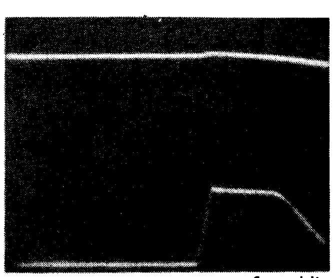


V_{DS} 200V/div

200 μs/div

Fig.4

HT voltage 5 kV/div



V_{DS} 200V/div

1 μs/div

Fig.5

Waveforms H/T voltage copper trace and drain